

## WHAT IS THE EFFECT OF HEAVY RAINS WITH HIGH WINDS ON THE RUN OF CUP-WHEEL ANEMOMETERS?

By CHARLES F. MARVIN

[Weather Bureau, Washington, September 1933]

Inquiry has been received as to the possible effect on the indications by cup anemometers of wind velocities due to the bombardment of rain drops under conditions of comparatively high winds and very heavy rains.

This is an interesting question which has perhaps not been very carefully investigated experimentally. Nevertheless, a seemingly conclusive answer is possible on analytical grounds.

Two obvious effects require consideration. First, the cups become thoroughly wetted by the addition of a certain amount of water and therefore slightly heavier. The second effect arises from the collisions with numerous water drops striking against both the concave and convex faces of the cups.

By measurement it is found that the actual weight of water on any of the cup wheels of the Weather Bureau anemometers amounts to 6.1 grams, which is 2.2 percent of the weight of the standard light-weight cups and, of course, a still smaller percentage of that of the heavier cup systems. Wind-tunnel tests with steady wind velocities show conclusively that when the length of the arms and other dimensions are the same the run of these anemometers is wholly independent of small changes in the mere weight of the cups. In the case of gusty winds the lag of the anemometer in following the wind is, of course, greater the greater the weight of the cups. For this reason heavy rain tends to make the cups lag behind the true wind velocity more than they do in the same wind without rain, and conversely when the wind velocity is falling off rapidly the cups overrun slightly. These effects are quite inconsequential on the average run of the cups. In other words, the effect of the increased weight of the cups due to rainfall may be regarded as negligible and unimportant.

As to the effect of the bombardment of the cups by the raindrops, reasoning indicates that the convex cups which are advancing in the wind collide with the raindrops at relatively high velocities. We are thinking here of the horizontal component of the motion of the raindrops with

reference to the surfaces of the cups at the instant of collision. The concave cups, however, are advancing *with* the wind and the kinetic energy involved in the collision of the raindrops and these cups because of the smaller relative velocities is certainly much less than the corresponding kinetic energies involved in the collisions of the raindrops with the convex cups. The ultimate result of these collisions must therefore be a tendency to retard the speed of rotation of the cups. As already stated, no wind tunnel or other measurements are available by which the amount of this retardation can be evaluated.

On the other hand, we do have carefully made measurements of the effects of moderate degrees of friction in retarding the motion of the cups as compared to the almost complete absence of friction. These friction tests show that even quite appreciable amounts of friction have an inappreciable or very small effect in retarding the speed of the cups in high winds and it is certain that the effects of the bombardment of the raindrops is quite appreciably less than the moderate amounts of friction which have been subjected to tests.

The final conclusions of the foregoing analysis are therefore (1) that rain tends to make the anemometer more sluggish by a very small amount in responding to fluctuating gusty winds, although the average run of the cups in such gusty winds is not appreciably affected and (2) that heavy rains in high winds retard the run of the cups substantially as does friction, but that the amount of this retardation, while not exactly known, certainly is inconsequential and unimportant.

We may conclude this consideration by asking how the cups would behave if exposed in perfectly still air during a heavy downpour of rain. A little analysis indicates that the action of the rain on each one of the cups would tend more or less to turn it backward. The combined force on all the cups might even be sufficient to actually turn a nearly frictionless anemometer cup wheel backward. In this way, too, falling rain tends to oppose motions caused by the wind.

## TROPICAL DISTURBANCES OF AUGUST 1933

By R. HANSON WEIGHTMAN

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The number of tropical disturbances this month was unusually large, 7 disturbances being reported, 4 of which were of slight intensity and 3 of hurricane intensity.

*August 12-20.*—The first disturbance of the month made its appearance in the region of Barbadoes, West Indies, whence it moved first west-northwest, passing south of Jamaica, then northwestward over Grand Cayman, thence more to the northward over extreme western Cuba, and finally northward to a point off the northwestern Florida coast where it lost intensity. The few reports available would indicate that the winds of this storm may have reached gale force while its center was south of Jamaica; otherwise, it was of minor consequence. Heavy rains attending thunderstorms, caused damaging floods in eastern Jamaica.

*August 16-21.*—A disturbance of slight intensity appeared over the Windward Islands on the 16th and moved westward. It was last traceable about 300 miles east of the Honduras coast on the 21st.

*August 17-26.*—This disturbance originated some distance to the east of the Windward Islands. It was first located from telegraphic reports on the morning of the 18th, about 900 miles east of Puerto Rico. The S.S. *Western Prince* in latitude 19°30' N., longitude 51° W., reported barometer 29.76 inches, wind northeast 42 m.p.h. with heavy southeast swell. It moved westward until the 18th, then followed a course northwest by north until the 21st, when it was central about 150 miles southwest of Bermuda, a maximum wind velocity of 64 miles from the east being reported at St. Georges. During the next 24 hours it bore more to the westward, with somewhat decreased speed and then turned to the northwest, passing nearly over but slightly to the east of Cape Hatteras, with lowest barometer 28.67 inches and maximum wind velocity 64 m.p.h. from the northeast. When the disturbance was about 150 miles southwest of Bermuda on the morning of the 21st, storm warnings were ordered between Cape Hatteras and Boston, with the information

that the tropical disturbance was of great intensity. On the morning of the 22d, these storm warnings were continued with the following information:

Tropical disturbance attended by fresh to strong gales, central about 350 miles southwest of Bermuda and same distance southeast of Cape Hatteras, direction of movement uncertain but probably will remain nearly stationary next 12 hours. Strong northeast winds probably reaching gale force off the coast.

At 4 p.m. of the 22d, storm warnings were extended south of Cape Hatteras to Southport, N.C. On the evening of the 22d, the following bulletin was issued:

Atlantic coast disturbances central about 150 miles southeast of Cape Hatteras, moving slightly north of west. Center will cross southern coast of North Carolina early Wednesday forenoon, preceded by dangerous shifting gales tonight between Virginia Capes and Southport, N.C. Advise all interests.

On the morning of the 23d the center was a few miles south of Norfolk, Va., where the pressure was 28.84 inches. It passed over Norfolk with lowest pressure 28.68 inches at 9:20 a.m. and a maximum wind velocity of 56 miles, while Cape Henry had a maximum velocity of 68 m.p.h. The center was near Washington, D.C., that evening, with a pressure of 28.94 inches. It moved northward to central Pennsylvania with decreasing intensity and then turned northeastward down the St. Lawrence Valley with further decrease in intensity.

This was one of the most severe storms that has ever visited the Middle Atlantic coast. It caused great damage in northeastern North Carolina, central and eastern Virginia, and in Maryland, Delaware, and portions of New Jersey, due to severe gales and high tides, largely the latter. While hurricane velocities were not actually recorded at any Weather Bureau station, it seems quite probable that along the coast between Delaware Breakwater and Cape Hatteras winds may have reached the lower limits of hurricane force (75 m.p.h.) for short intervals. Warnings of high tides for the Norfolk area were given out preliminarily as early as the 21st and more specifically and positively during the afternoon and evening of the 22d. A tide of 7 feet above normal occurred, flooding the downtown business section of Norfolk as never before. The official in charge at Norfolk reports that plate-glass windows were broken in the business section by the wind, and states that:

Loss to shipping in this remarkably severe storm, which has been characterized as the worst ever experienced in this section, was practically negligible. The warnings were so widely disseminated that vessels stayed in port, or sought shelter if at sea, except in 1 or 2 cases. \* \* \*

A great deal of damage resulted to resorts on the Virginia, Maryland, Delaware, and New Jersey coasts and also in Chesapeake Bay. Power, telephone, and telegraph services were disrupted for a time in portions of Delaware southward to Cape Charles. An extract from the report of the Weather Bureau official at Baltimore, gives details regarding the extent of the damage in the State of Maryland:

The damage to property, exclusive of crops, is estimated to be in excess of \$10,000,000, and to crops about \$7,000,000. Crop damage in Maryland alone, estimated by the State Experiment Service of the University of Maryland, from the reports of county agents, was as follows: Tobacco crop, more than \$1,500,000 (Baltimore tobacco experts estimate \$2,000,000, including stocks in warehouses); tomatoes somewhat more than \$1,000,000; corn crop, including loss of fodder, more than \$2,000,000. Worcester County suffered the most damage to the corn crop \$300,000. The least was \$6,000 in Allegany County.

The fisheries industry was injured severely, the amount being difficult to estimate but probably around \$3,000,000. Many boats were destroyed and a larger number sunk and damaged, buildings and wharves were wrecked, etc. At Crisfield, Md.,

alone, the damage to the industry was \$100,000. The damage to highways was \$406,851 in Maryland and \$150,000 in Delaware. Railroads suffered a property loss of about \$555,000; telephone and electric companies about \$364,000; Federal buildings and works probably about \$1,100,000 (Naval Academy at Annapolis alone \$90,000); passenger, freight, and pleasure boats and establishments about \$392,000 (Maryland Yacht Club at Baltimore in excess of \$60,000); miscellaneous damage to dwellings, pleasure resorts, coast towns, etc., about \$2,000,000; shore land lost in Maryland by wave action (estimated by State conservation commissioner) about 2 square miles; in Delaware about 1 square mile.

*August 24-30.*—A disturbance of slight intensity first appeared on the 24th, central apparently about 340 miles north by east of Antigua, West Indies. It moved northwestward during the following 2 days, then recurved to the northward and passed about 160 miles west of Bermuda during the night of the 27th. By the morning of the 30th it was central about 250 miles south of Cape Race, Newfoundland, moving northeastward.

*August 27-29.*—A disturbance of slight intensity developed in a region of unsettled weather over Mexico near Frontera during the 26th and 27th. From vessel reports subsequently received, it apparently moved northwestward to the vicinity of Tampico by the 28th attended by heavy rains at Mexican coast stations but without strong winds. By the evening of the 28th, available vessel observations over the northwestern Gulf showed that the wind velocities had increased to 22 m.p.h., and shifted from northeast and east to southeast. Consequently, on the morning of the 29th, with the uncertainty regarding the advance of the center northward, storm warnings were ordered from Port Arthur to Corpus Christi, as follows:

Tropical disturbance of slight intensity about 125 miles southeast of Corpus Christi apparently moving northward; will cause fresh to strong northeast winds late this afternoon and tonight, with strong shifting winds over very small area around center.

Special observations received during the afternoon of the 29th showed rather definitely that the center was south of Brownsville and at 9 p.m. storm warnings were ordered down.

*August 28-September 6.*—This disturbance first appeared the evening of the 28th, a short distance northeast of the Windward Islands. By the morning of the 29th, ship reports showed that it was attended by gales and moving west or west-northwest. It continued to move west by north, passing slightly north of Turks Islands with lowest barometric pressure at Grand Turk of 29.41 inches at 3 p.m., of the 30th, and maximum wind of 56 miles from the southwest. By the following morning its center was a short distance southwest of Crooked Island, Bahamas, and 24 hours later near Sagua la Grande on the north coast of Cuba, attended by winds of hurricane force.

On the evening of the 30th, storm warnings were ordered for southern Florida.

During the late afternoon of September 1, the barometer at Habana read 28.92 inches as the storm center passed a short distance north of the city. The highest wind velocity at Habana was 94 m.p.h. from the south, while at Key West, Fla., the maximum was 42 m.p.h. from the east. Little damage was done at Key West, but, according to press reports there was considerable loss of life and much property damage along the north coast of Cuba and probably also some distance inland.

Moving westnorthwestward across the Gulf of Mexico, the storm center reached the ninety-fifth meridian, approximately 150 miles east of Brownsville, Tex., the morning of September 4, after which it moved directly westward, and passed inland just north of Brownsville

the following night. Brownsville reported a barometer reading of 28.02 inches at 1:30 a.m. of the 5th, and an estimated maximum wind of 80 m.p.h. from the northwest earlier in the night. According to an Associated Press dispatch from Brownsville there were 22 known deaths and property damage running into millions of dollars in the area from Corpus Christi to some distance south of Brownsville in extreme northeastern Mexico. However, no lives were lost in either Brownsville or Corpus Christi. The remarkable escape of Brownsville citizens was attributed to the fact that all had ample warning that the tropical hurricane was approaching the city.

Realizing that the storm was a major hurricane and that the week-end holiday would extend over Labor Day, the district forecaster sent the following warning to all Texas coast stations on the morning of Saturday, September 2:

Uncertain where tropical storm in Gulf will reach coast line, but all persons should be warned to remain away from inaccessible places on Texas coast over week end.

That the warning was heeded was attested by the following excerpt from the report of the official in charge, Corpus Christi, Texas:

\* \* \* Probably never before in the history of Texas hurricanes have such widespread and early warnings been given as were received from Washington in advance of this one. The telegram of Saturday, September 2, warning all persons to avoid

inaccessible places over the week end probably saved thousands of lives. Major Swan, owner of the Don Patricio Causeway, estimated that between 2,500 and 4,000 visitors would have passed over the causeway to Padre Island during Sunday and Monday had it not been for the timely warning sent out from the central office. The same is true of Mustang Island, Bird Island, and the many other places north and south of this city. It is not an exaggerated estimate to state that between 6,000 and 10,000 persons might have been in inaccessible places had it not been for the advance warning to stay away from those places. \* \* \*

At 10 p.m. of September 3, hurricane warnings were ordered displayed from Corpus Christi to Freeport and storm warnings on the remainder of the Texas coast. The storm at this time was central about 300 miles due east of Brownsville and still moving west-northwestward. No reports were received from the vicinity of the storm the morning of the 4th, but when it became apparent during the late afternoon and evening that the storm was moving directly westward and would reach the coast not far north of Brownsville, hurricane warnings were ordered south of Corpus Christi to Brownsville, while the hurricane warnings north of Corpus Christi were changed to storm warnings.

*August 31-September 5.*—On the morning of the 31st, another tropical disturbance was about 225 miles north-northeast of Antigua, West Indies. It subsequently passed over Florida. An account of this disturbance will appear in the September issue of the Monthly Weather Review.

## BIBLIOGRAPHY

C. FITZHUGH TALMAN, in charge of library

### RECENT ADDITIONS

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